Sunyaev-Zel'dovich Surveys, the South Pole Telescope (SPT), and Onwards

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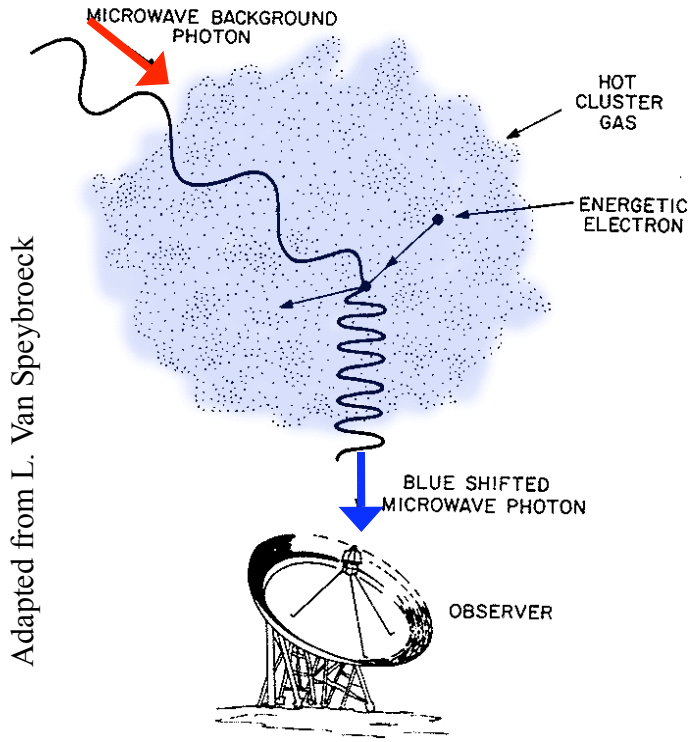
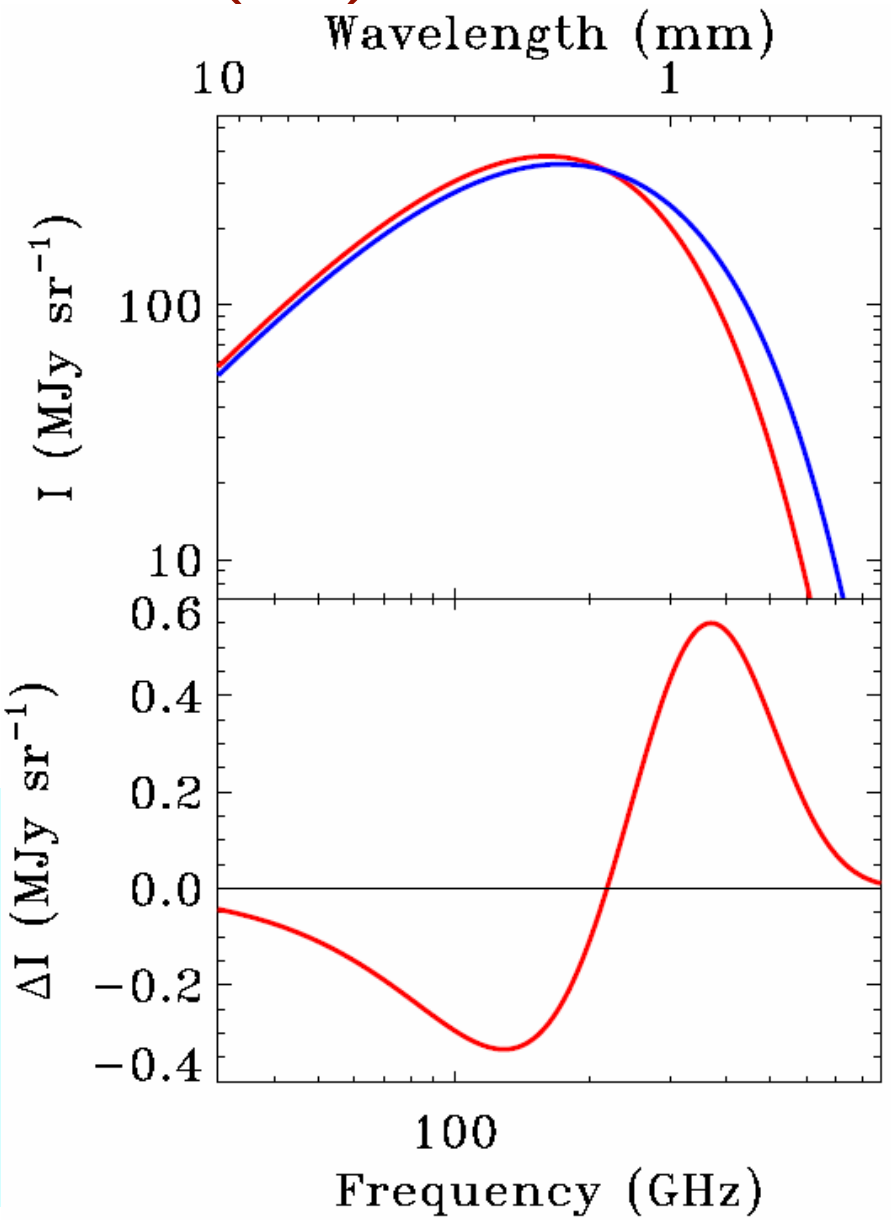
Outline

1. Science
   - The Sunyaev-Zel'dovich (SZ) Effect
   - Constraining Cosmology with SZ Cluster Surveys
2. The South Pole Telescope (SPT) Project
   - Description, Results, & Synergies with Other Surveys
3. Other SZ Surveys and Onwards

The Sunyaev-Zel'dovich (SZ) Effect





- 1-2% of Cosmic Microwave Background (CMB) photons scatter off of hot intra-cluster gas to higher energy, this is the **Sunyaev-Zel'dovich (SZ) Effect**
- SZ surface brightness is redshift independent

Cosmology with Clusters of Galaxies

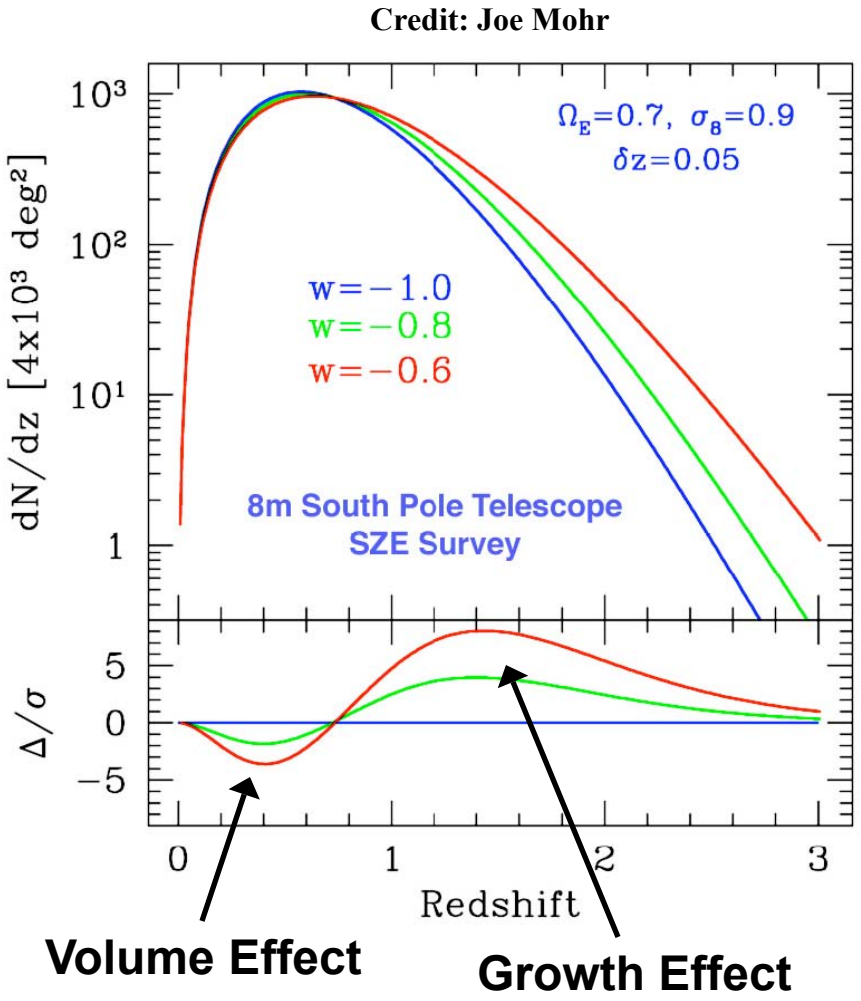
Cluster Abundance, dN/dz

$$\frac{dN}{d\Omega dz} = n(z)\frac{dV}{d\Omega dz}$$

Depends on:
Matter Power Spectrum, *P(k)*
Growth Rate of Structure, *D(z)*

Depends on:
Rate of Expansion, *H(z)*

For fixed Ω_{DE} and increasing *w*:
1. Less clusters at low redshift, due to decreased volume surveyed
2. More clusters at high redshift, due to decreased growth rate

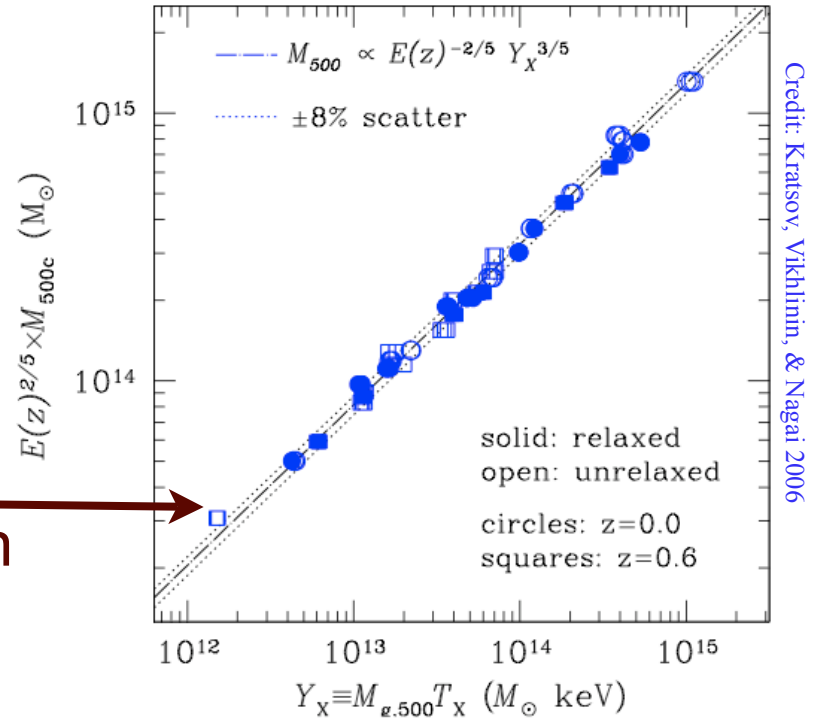


SZ Cluster Survey Advantages

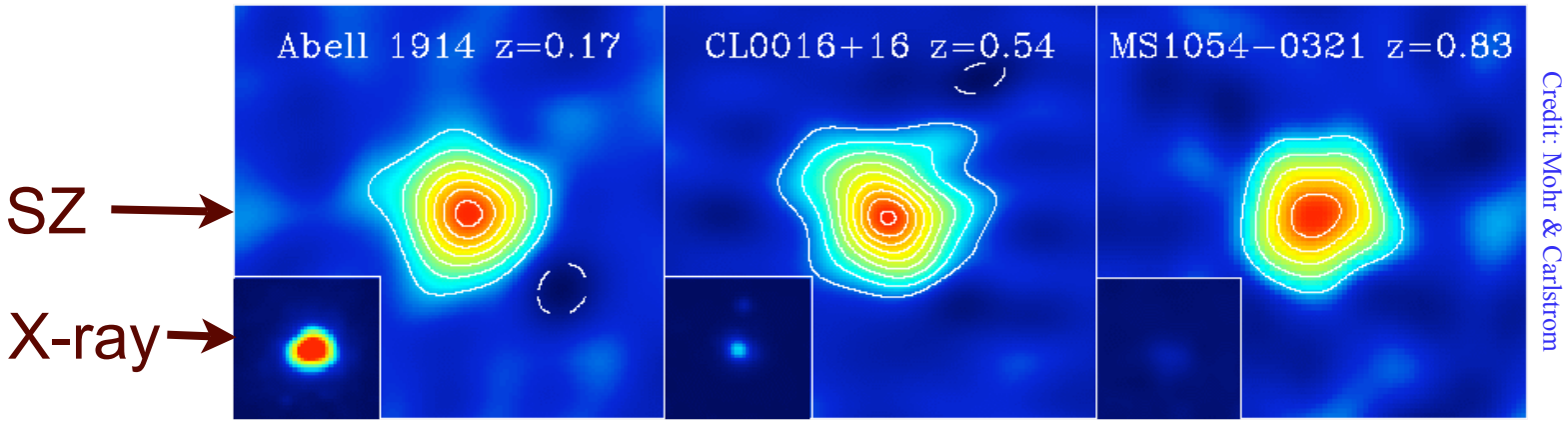
1) IC gas pressure is a "clean" mass estimator

2) Complete survey out to high redshift

~8 pct scatter in Mass vs Integrated Pressure Relation



Credit: Kratsov, Vikhlinin, & Nagai 2006



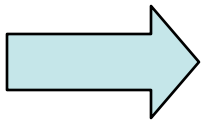
Credit: Mohr & Carlstrom

Same range of X-ray surface brightness and SZ decrement in all three insets.

Requirements for a SZ Survey Experiment

- **Spatial Resolution**
  - 1’ is well-matched to typical cluster size at these redshifts
  - At 150 GHz this means you need a 8-10 meter dish

- **Mapping Speed**
  - (# of elements) / noise^2
  - At 150 GHz (from the ground), bolometers have reached photon background limit to sensitivity
  - Typical SZ/CMB instruments have on the order of tens of pixels (e.g. - QUAD = 31 pixels, Bolocam ~ 120, ...)



Need More Detectors!!!

The South Pole Telescope (SPT)

Sub-millimeter Wavelength Telescope:

- 10 meter telescope (1' FWHM beam at 150 GHz)
- 20 microns RMS surface accuracy
- Off-axis Gregorian optics design
- Two levels of ground shielding
- 1 arc-second pointing
- Fast scanning (up to 4 deg/sec in azimuth)

1st Generation Camera:

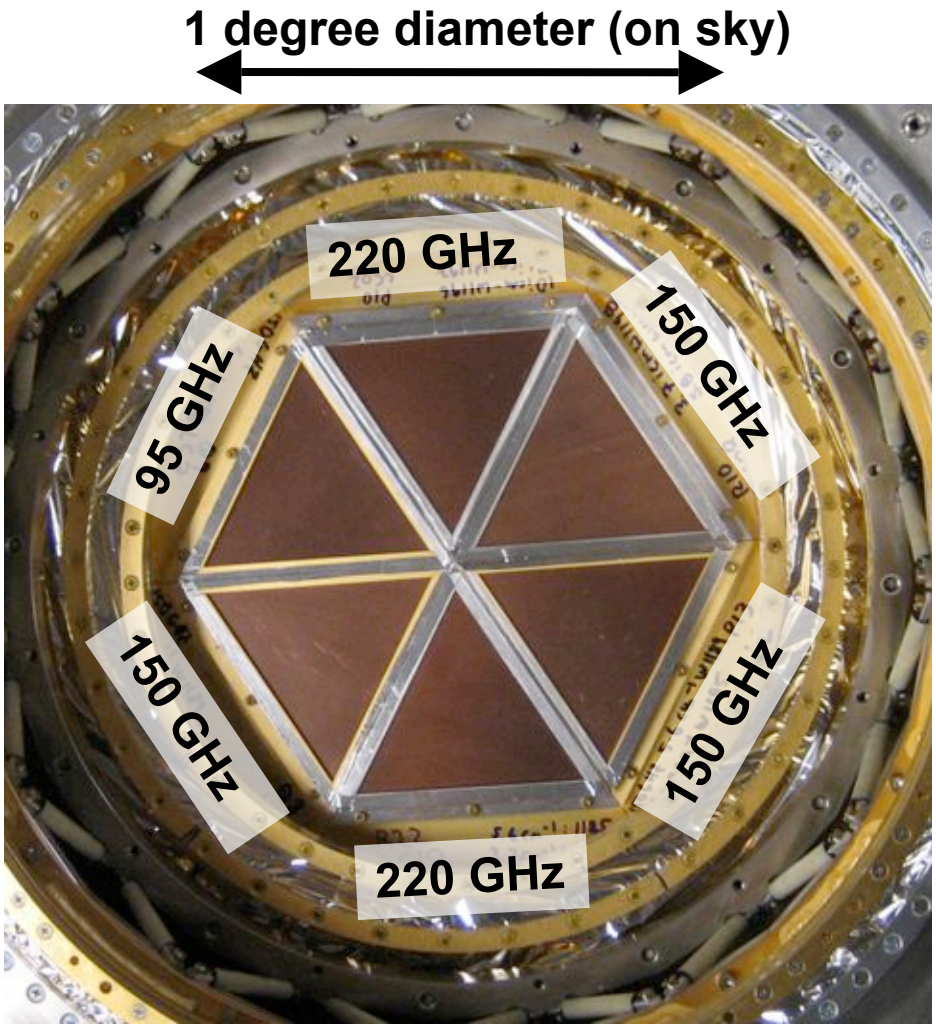
- 1 sq. deg FOV
- ~1000 pixels
- Observe in 3+ bands between 90-220 GHz simultaneously with a modular focal plane

Funded by NSF

SPT 1st Year Deployment
January 2007


KICP
Kavli Institute
for Cosmological Physics
AT THE UNIVERSITY OF CHICAGO
Berkeley
University of California
Case
CASE WESTERN
RESERVE UNIVERSITY
THE UNIVERSITY OF
CHICAGO
UCDAVIS
UNIVERSITY OF CALIFORNIA
ASTRONOMY
UNIVERSITY OF ILLINOIS
AT URBANA-CHAMPAIGN
McGill
VE RI
TAS
Harvard-Smithsonia
Center for Astrophysi
CARDIFF
UNIVERSITY
PRIFYSGOL
CAERDYDD
Colorado
University of Colorado at Boulde
BERKELEY LAB
SPT Collaboration May 2008

SPT Focal Plane



- Modular design of SPT focal plane into 6 wedges is useful to allow multiple frequencies
- 1st year:
  - **2x 95 GHz**, **3x 150 GHz**, and **1x 220 GHz** wedges
- 2nd year:
  - **1x 95 GHz**, **3x 150 GHz**, and **2x 220 GHz** wedges
- Next season plan to add more 95 GHz detectors to improve SZ mapping speed

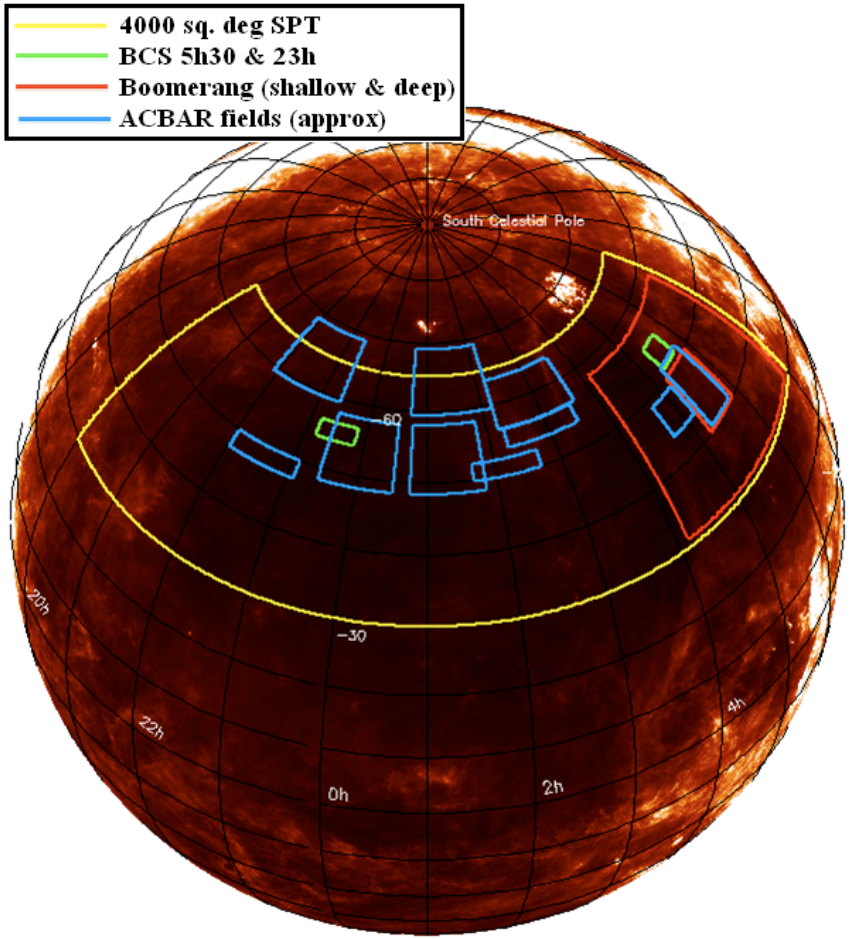
SPT Observing Region

South Pole Telescope – SZ Survey:

- ~4000 sq. deg. Survey (2007-2010)
- South of -30^{o} declination

What we have so far:

- **BCS Fields:** ~200 sq. deg down to ~0.7 mJy at 150 GHz, and ~2.8 mJy at 220 GHz per 1 arcmin beam
- **WMAP Fields:** ~700 sq. deg, faster larger scans to calibrate off CMB for ~2 pct calibration
- **Targeted Clusters:** Deep observations of ~25 known massive clusters with existing X-ray data



SPT Collaborating Photometric Surveys

Stage I: Blanco Cosmology Survey (BCS)

- A 45 night program that began fall 2005 to survey 100 square deg (2.5 pct of SZ survey size) at Blanco 4m on Cerro Tololo
- http://cosmology.uiuc.edu/BCS (Mohr)

Blanco 4m on Cerro Tololo

Image credit: Roger Smith/NOAO/AURA/NSF

Stage II: Targeted Photo-z's

- PISCO (Magellan), Spitzer, ...

Stage III: Dark Energy Survey (DES)

- 5000 square deg G, R, I and Z bands
- 2005-2010: Construction of a new 3 square deg camera for the Blanco 4m
- 2010-2015: Survey Operations
- https://www.darkenergysurvey.org/

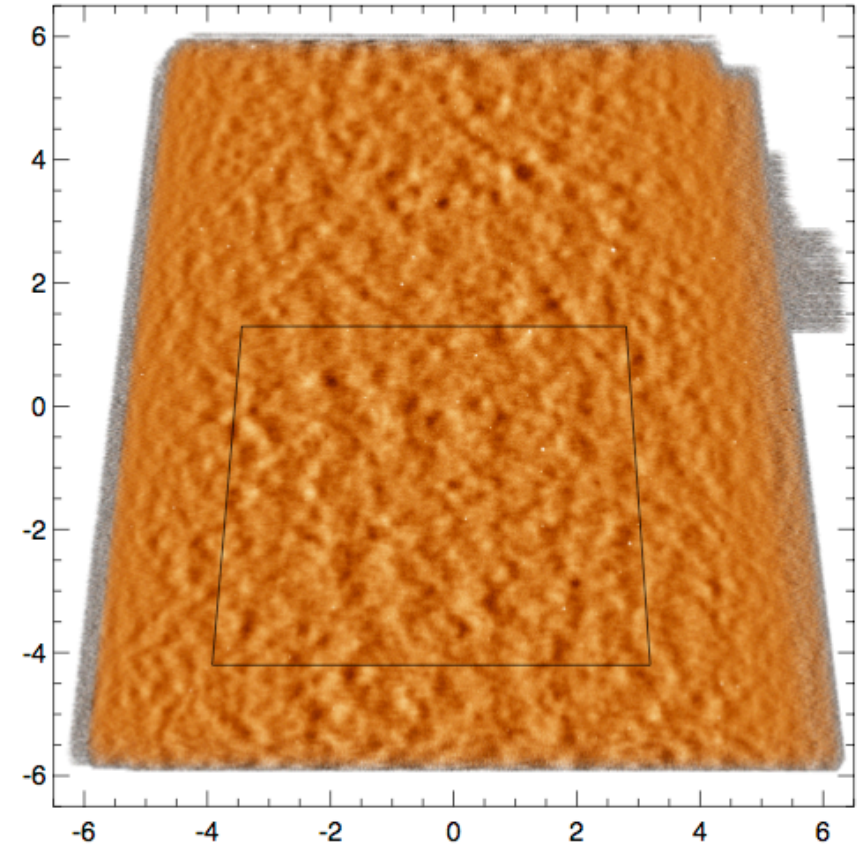
John Peoples, Director

Collaboration of: Fermilab, U Illinois, U Chicago, LBNL, CTIO/NOAO, Barcelona, UCL, Cambridge, Edinburgh, U Michigan, UPenn, Brazil

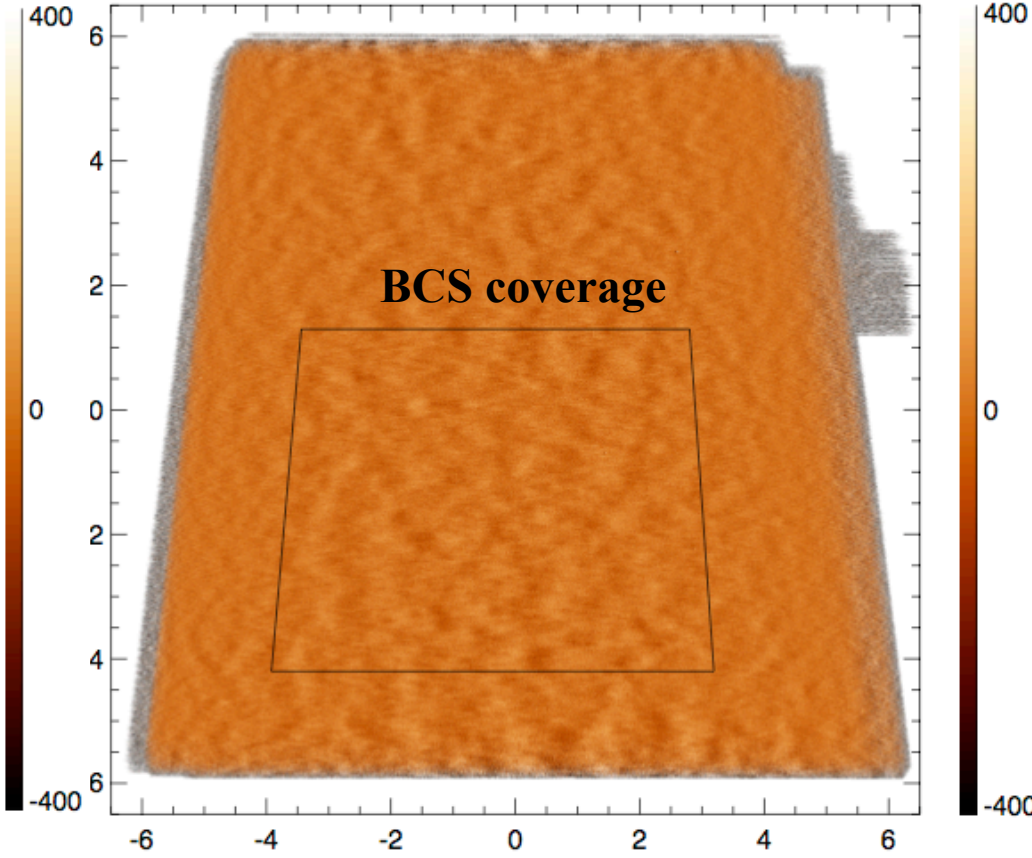
RA 5hr30min BCS Field

- Mapped with interleaved azimuth raster scans
- ~800 hours of observation
- 100 deg^2 ~17 uK CMB/arcmin pixel
- 40 deg^2 overlap with BCS

150 GHz L+R map



150 GHz L-R map

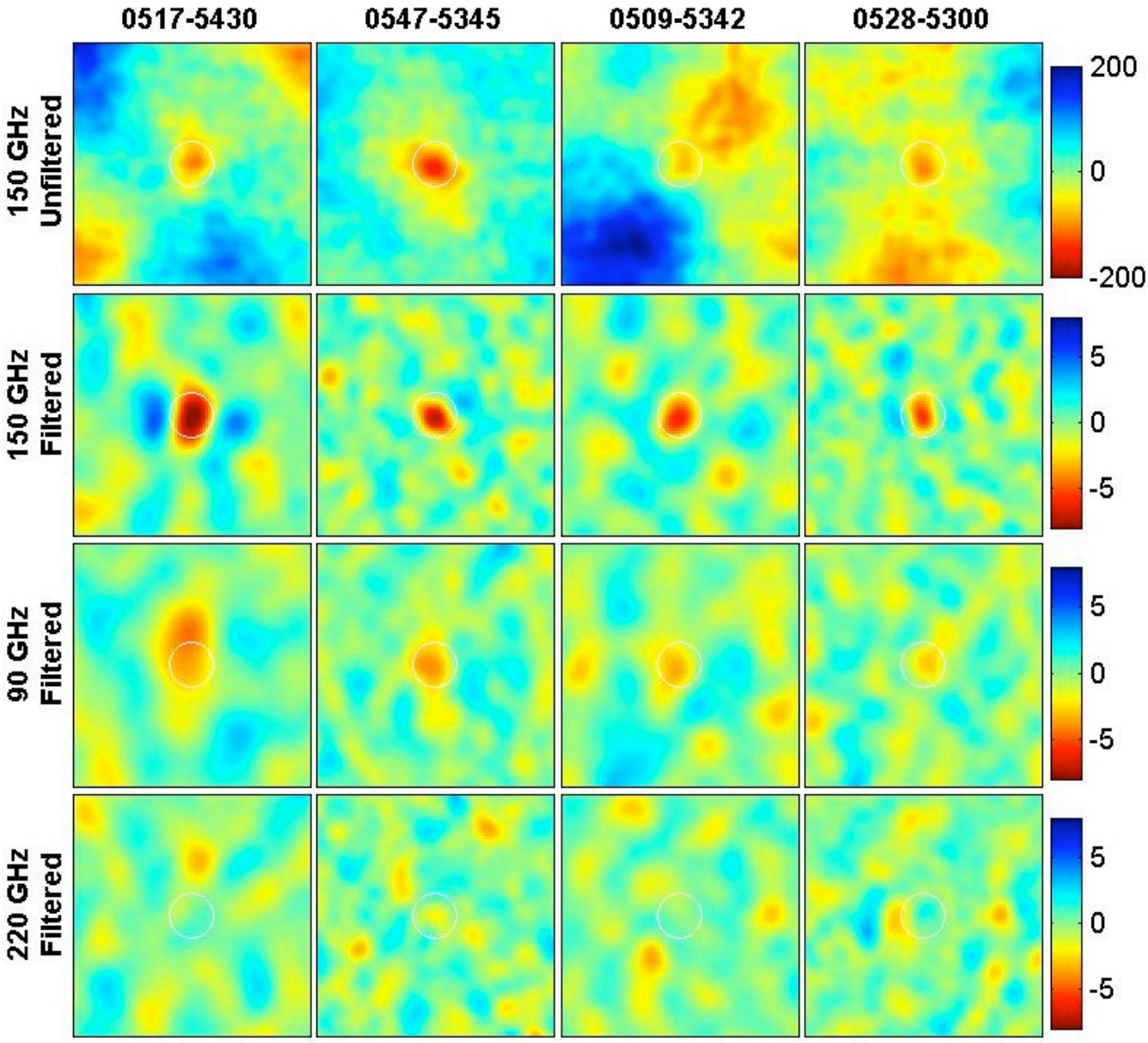


SZ Discovered Clusters

- The 4 most significant detections in the BCS overlap region

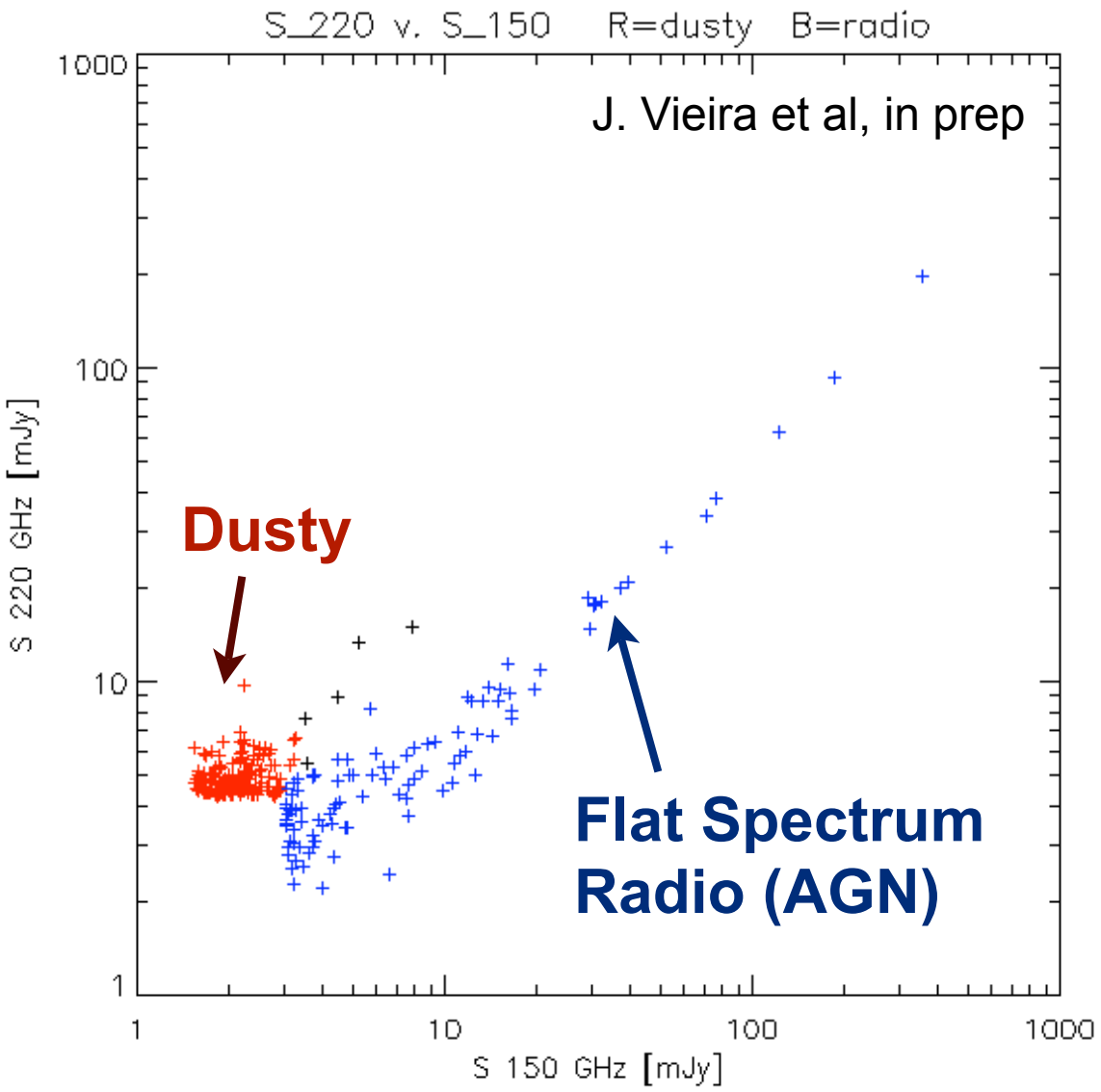
Staniszewski et al., astro-ph/0810.1578

- Brightest cluster is a known ROSAT cluster
- All 4 have optical confirmations
- Many more clusters in fields, but need:
  - optical confirmation
  - X-ray + lensing studies to understand mass calibration

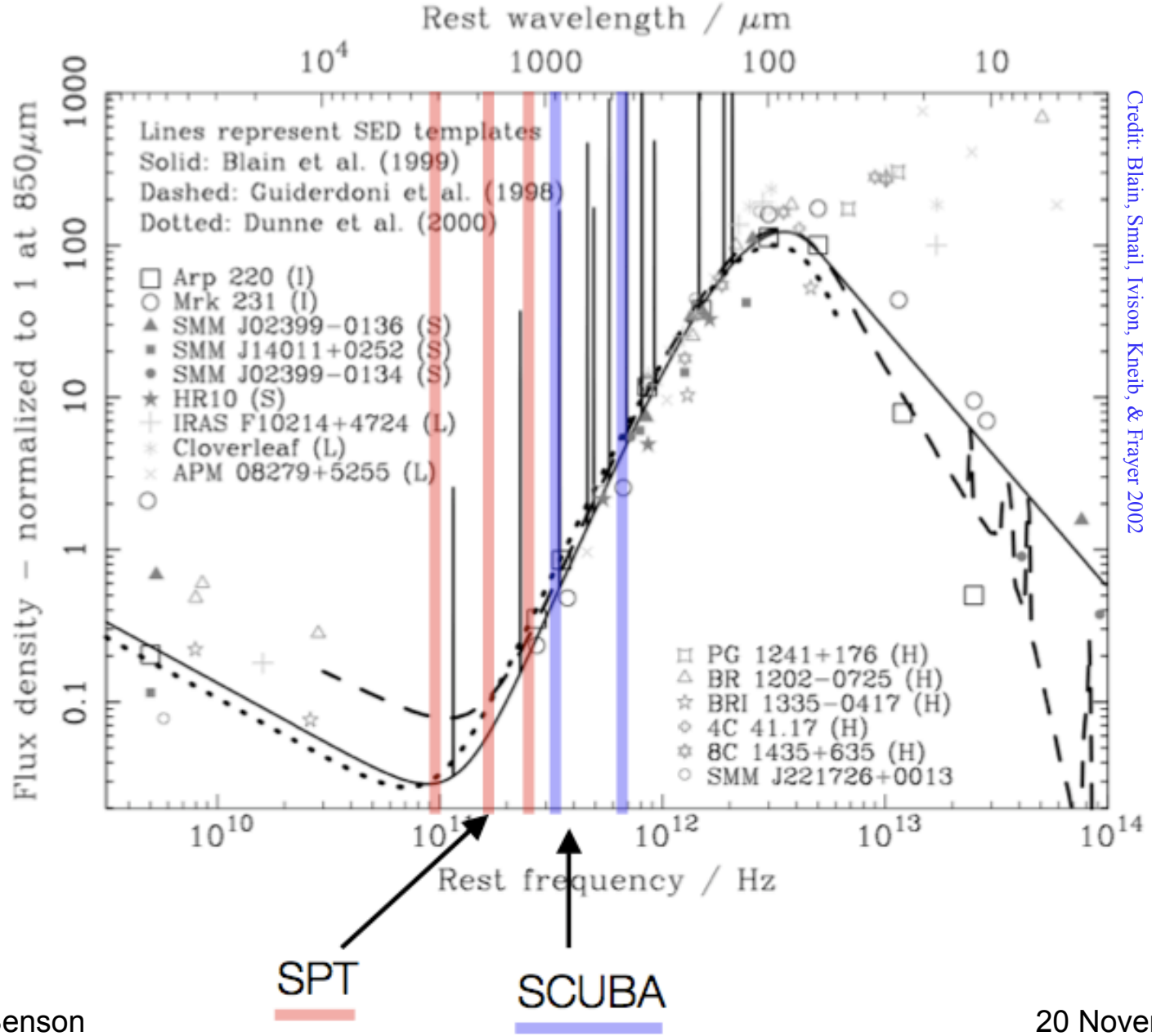


Point Sources

- In ~800 hours of observations on ~100 deg^2, SPT 150 GHz flux limit is ~0.7 mJy
- Hundreds of point sources in 100 sq deg SPT Map
- 5-sigma flux limit of ~3.5 mJy at 150 GHz, and 3-sigma flux limit of ~4.5 mJy at 220 GHz
- Almost all dusty sources unidentified, likely SCUBA-like submm bright dusty galaxies at high redshift
- Future ALMA sources



Spectral Energy Density of a Dusty Galaxy

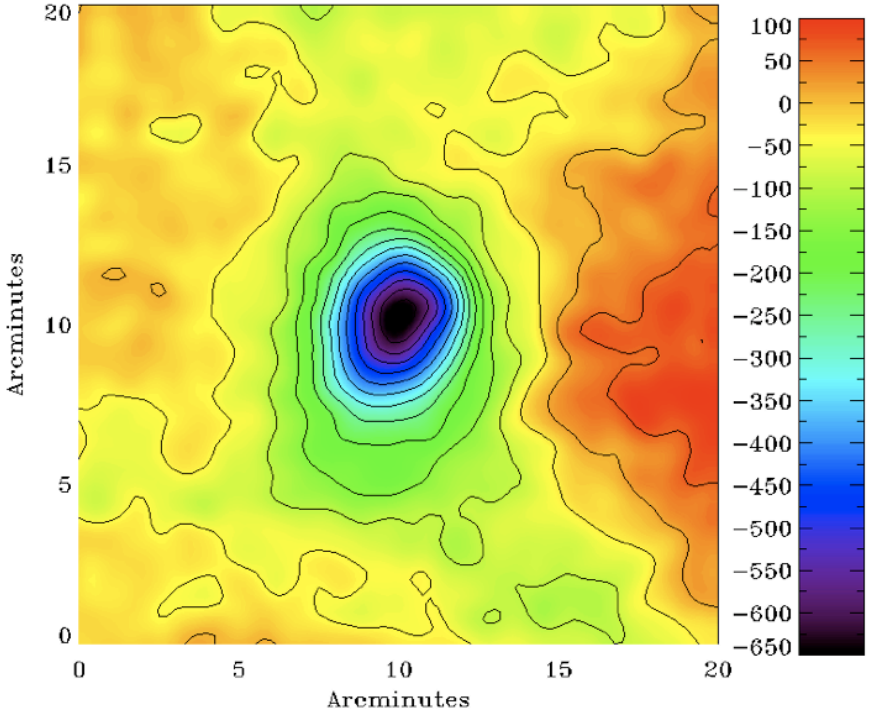


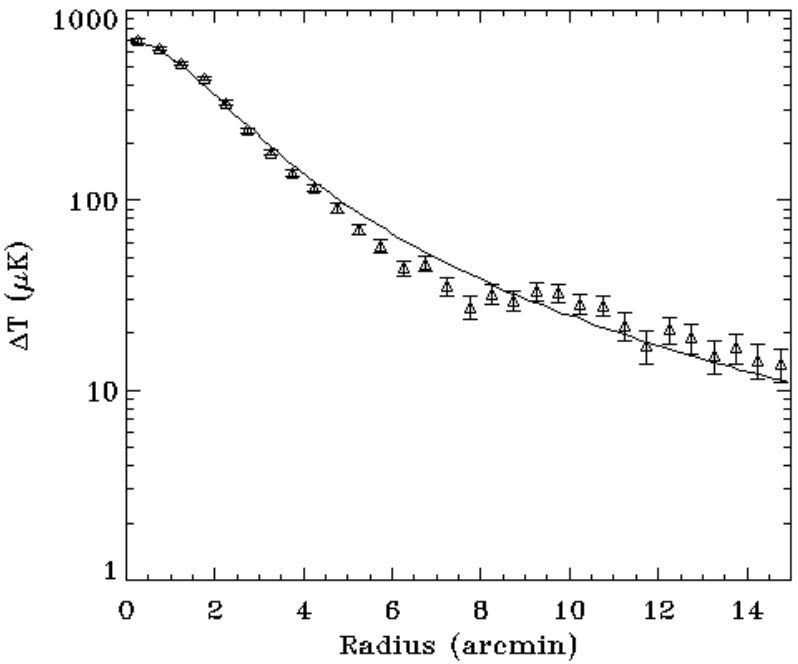
Credit: Blain, Smail, Ivison, Kneib, & Frayer 2002

Bullet Cluster

13 hour SPT observation
~13 uK noise -> 50 sigma detection!

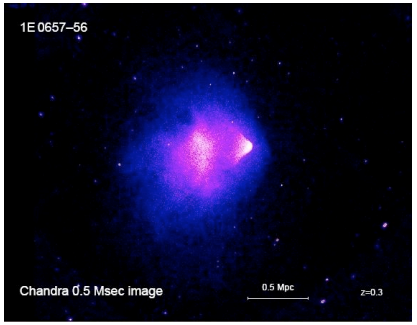
Significant signal out to ~15 arcmin
r_200 is ~8.5 arcmin for this cluster





T. Plagge et al, in prep

Chandra
140 hrs obs
(Markevitch)



same scale
as SPT image

Other SPT Cluster Observations

SPT Hours Observed	Name	J2000 RA	J2000 Dec	z	LCDM, h=0.7 Lx(0.1-2.4) (1e44 ergs/s)
12	A2744	00:14:19	-30:23:00	0.3066	12.92
6	RXJ0217	02:17:13	-52:44:49	0.3432	12.0
6	RXJ0220.9	02:20:57	-38:28:48	0.228	5.82
12	RXJ0232.2	02:32:17	-44:20:51	0.2836	9.65
6	A3084	03:04:04	-36:56:27	0.219	4.68
6	RXJ0336.3	03:36:16	-40:37:45	0.1729	5.3
6	A3292	04:49:57	-44:40:24	0.150	3.29
bcs + 6	RXJ0516	05:16:38	-54:30:51	0.2952	13.87
6	RXJ0528	05:28:56	-39:27:46	0.2839	13.12
12	RXJ0532	05:32:55.5	-37:01:28	0.2708	6.94
6	CLJ0542.8	05:42:50	-41:00:02	0.634	9.9
6	A3364	05:47:38	-31:52:25	0.148	4.67
6	MACSJ0553	05:53:27	-33:42:53	0.407	32.68^{bolo}
9	RXJ0638	06:38:46.5	-53:58:18	0.2266	10.62
6	A3404	06:45:29	-54:13:08	0.1644	7.360
7 (+ 6)	Bullet	06:58:31	-55:56:49	0.297	23.03
12 (+4)	MACS1931	19:31:49.6	-26:34:34	0.352	
6	RXJ2011	20:11:23	-57:25:39	0.279	7.23
9	A3667	20:12:24.3	-56:49:49	0.053	5.41
6	RXJ2031	20:31:52	-40:37:14	0.3416	12.04
15	MACS2046	20:46:00.5	-34:30:17	0.423	
6	RXJ2218.6	22:18:40	-38:53:51	0.141	3.78
6	A3888	22:34:31	-37:44:06	0.151	8.46
9 (+ 6)	AS1063	22:48:43.5	-44:31:44	0.348	30.78

- 24 known clusters detected with SPT
- Almost all have Chandra or XMM data
- Any lensing data? Nine in LoCuSS sample (Graham Smith et al.), which combines X-ray + lensing
- Optical velocity dispersions?
- Will be an interesting sample to study:
  - outer regions of clusters (gas mass fraction vs. radius, temperature vs radius)
  - gas & mass dynamics
  - peculiar velocities (dark flows?)

Other SZ Surveys

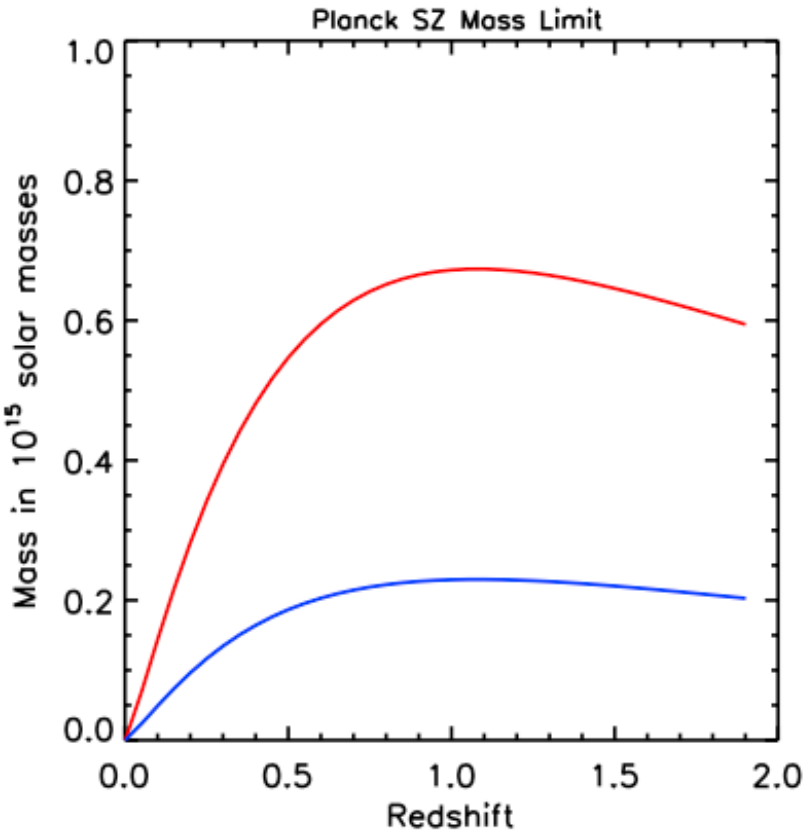
ACT:

- 6 m telescope in Chile
- 150, 220, 280 GHz
- Started regular operations in ~June 2008
- Plans to survey ~1000 sq deg

Planck:

- Launch: 2009
- Transfer to orbit: 3-4 months
- 2 full-sky surveys: 14 months
- Data release: + 2 years
- 9 bands between 30-850 GHz, allows CMB & SZ separation

Ref: Planck Blue Book



but low (9' - 5') resolution of 1.5 meter limits cluster sensitivity

Planck Figures courtesy J. Bartlett & J. Carlstrom

Conclusion

- Deep, large, 1' resolution maps are now being made by SPT. Should have of order 1000 degrees mapped out in the next two years at 90, 150, and 220 GHz
- ACT and Planck are on the horizon as well
- Joint analyses with X-ray and lensing to study:
  - cluster masses
  - thermal evolution of IC gas
  - baryonic + dark matter dynamics
- Sub-mm and radio follow up of point sources:
  - star formation and dusty galaxy history
  - AGN evolution